

FLOW OF WATER IN PIPES AND TUBES

-GRAPHS FOR DIRECT DETERMINATION

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The problem of determining flow, pressure requirements, and temperature rise of water-cooled devices is repeated so many times at an accelerator installation that a computer program, Flow was set up around a rapidly-converging algorithm for solving the Colebrook equation. The success of the program suggested its extension to the preparation of a set of graphs that could become a part of the engineer's handbook. Three such sets were prepared, one for smooth tubes, another for iron pipe and a third for galvanized pipe.

Predetermination of the relationship between the diameter of the water passage, the surface roughness of the passage, the rate of flow and the pressure requirements has been subject to some confusion and, at best, a time-consuming calculation. Furthermore, the results of calculations using Williams' method do not always agree with similar calculations using Moody's² method. Inasmuch as both methods are semi-empirical, the choice was made on the basis of the large amount of supporting data for the latter^{4,5}.

Seeking a practical system for obtaining a reasonably accurate solution that involved only simple algebra, Dr. Moody² developed a set of graphs that have been reproduced in handbooks and rather generally used. Although the graphs are simpler to use than a trial-and-error procedure, problems such as the calculation of the hole size for a magnet coil still involve tedious solution of the trial-and-error type. Dr. Moody, and other authors, have stopped short of plotting pressure drop as a function of flow only and leave it to the engineer to compute Reynold's Number,

An asterisk in the printout indicates that the flow is in this region. The computer data was ignored when plotting the graphs through the unstable region and replaced with a smooth dotted curve.

Fortunately there are few cases where flow falls in the unstable region.

Once the friction factor has been found the pressure drop for one hundred feet of the pipe or tube is computed from the equation,

$$P = 1.34 f G^2 D^{-5}$$

Use of the Graphs:

The graphs are self-explanatory but some caution is advisable when using them, for example:

1. The hole size, unless special tolerances are in effect, may vary considerably. Flow for a given pressure drop is approximately proportional to $D^{5/2}$ hence the per cent change in flow is roughly $2\frac{1}{2}$ times the per cent error in the diameter of the hole.

2. It is difficult to determine the effect of bends in the tubing or pipe; common practice is to approximate the effect of bends and offsets by adding two feet of length per turn when computing flow in coils.

3. There may be some degradation of the flow path after a few years service.

Although the computed values agree quite well with experimental results, a five or ten per cent margin in flow is advisable when designing cooling circuits that have a critical temper-

ature rise that cannot be exceeded.

The accuracy of the Graphs has been checked for a few magnet coils at NAL and also against published flow data for commercial pipe as follows:

Smooth Tubing

<u>Sample</u>	<u>Hole Size</u>	<u>Press. Drop</u>	<u>Gallons per Minute</u> <u>Calculated</u>	<u>Measured</u>
B1-Inner	0.40"	200 psi.	6.18	6.2
B1 Outer	0.27"	200 psi.	4.1	4.0
B2 Inner	0.27"	200 psi.	4.1	3.95
B2 Outer	0.455"	200 psi	7.1	7.35

Iron Pipe

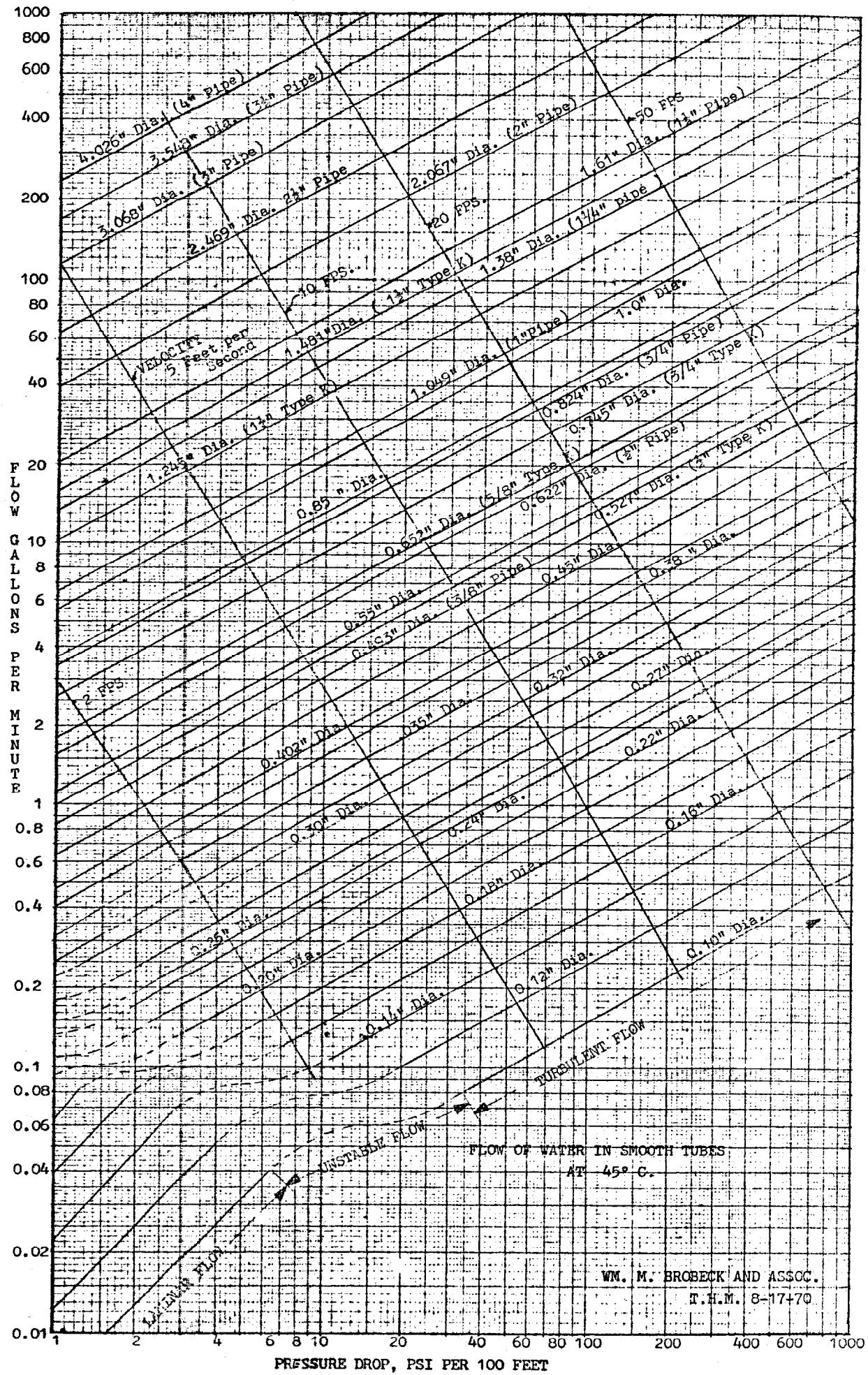
<u>Size</u>	<u>I.D. In.</u>	<u>100'</u> <u>Press.</u> <u>Drop</u>	<u>Gallons per Minute</u>	
			<u>"Flow"</u>	<u>Crane Co.</u>
$\frac{1}{4}$ "	0.364	0.359	0.23	0.2
1"	1.049	0.835	5.05	5.0
1"	1.049	2.99	10.1	10.0
1"	1.049	41.5	40.5	40.0
$2\frac{1}{2}$ "	2.469	0.158	20.7	20.0
$2\frac{1}{2}$ "	2.469	0.556	40.4	40.0
$2\frac{1}{2}$ "	2.469	2.03	81.0	80.0
$2\frac{1}{2}$ "	2.469	14.63	225.	225.

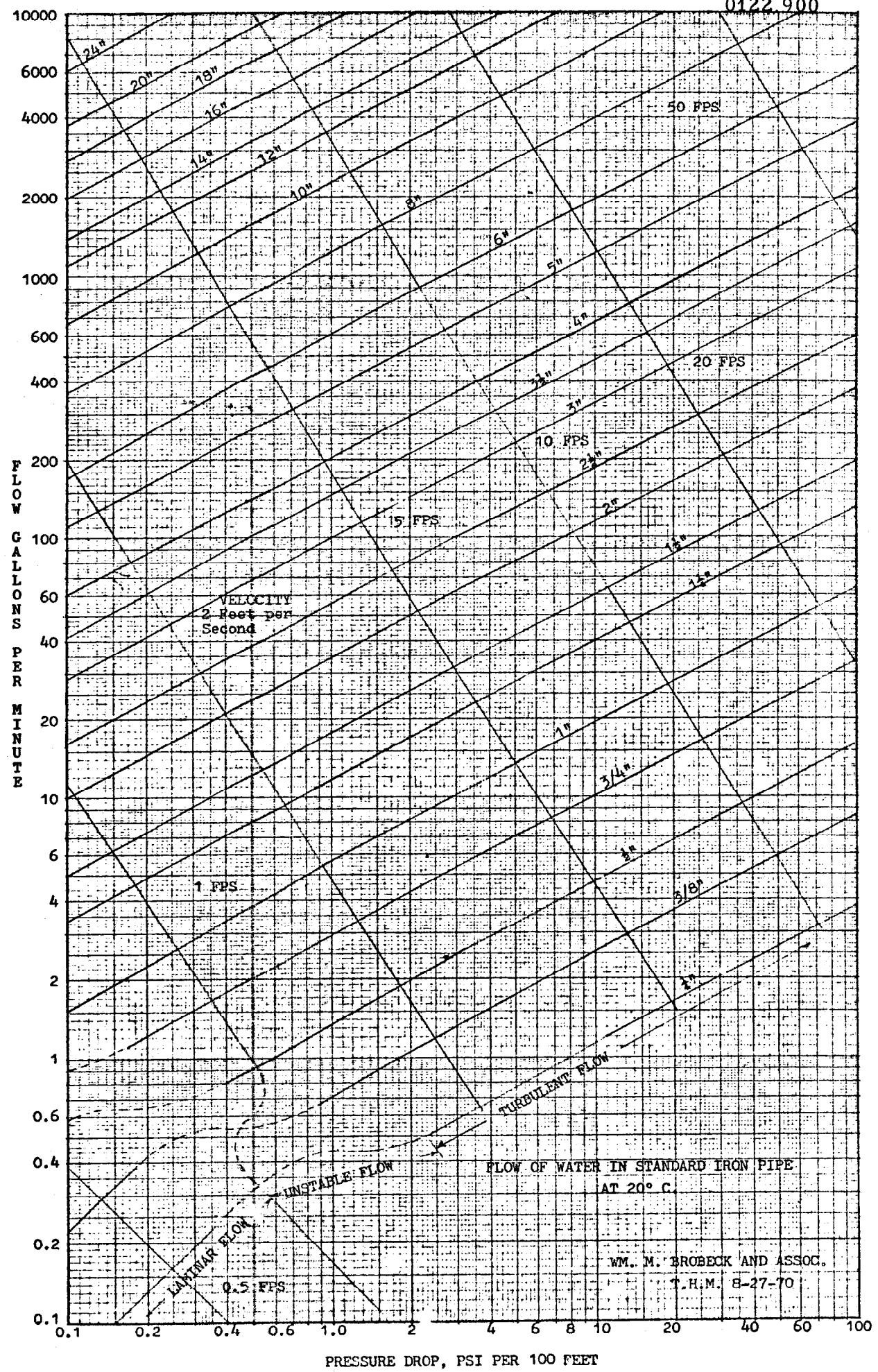
References

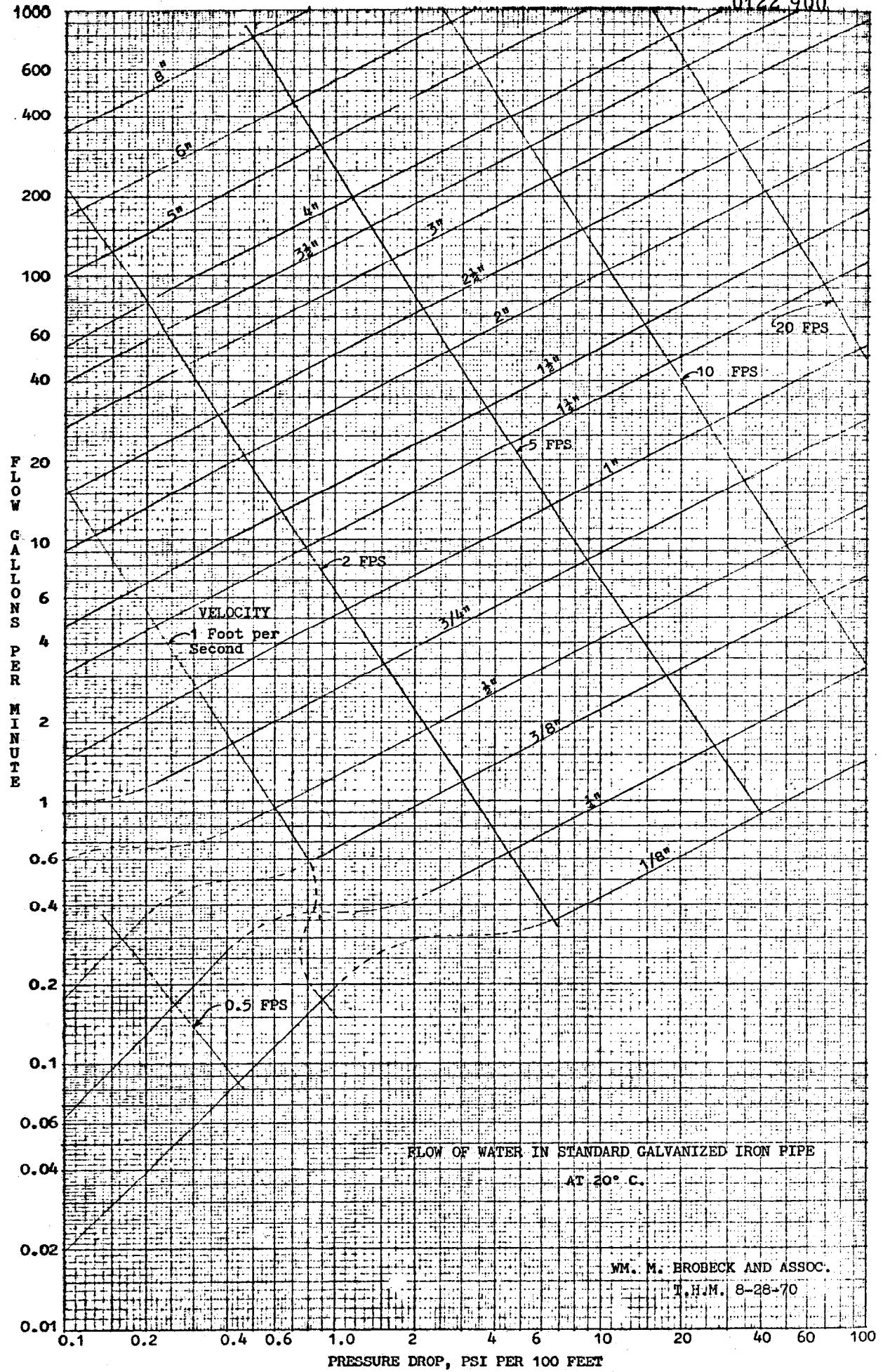
1. G. S. Williams and A. Hazen, Hydraulic Tables, Wiley 1933.
2. Lewis F. Moody, Friction Factors for Pipe Flow, Transactions of the A.S.M.E., Nov. 1944, pp. 671-684.
3. Design and Drafting Manual, University of California Radiation Laboratory.
4. C. F. Colebrook, Turbulent Flow in Pipes, with Particular

Reference to the Transition Region Between the Smooth and Rough Pipe Laws, Journal of the Institution of Civil Engineers, (London), Vol 11, 1938-39, pp. 133-156.

5. H. Rouse, Evaluation of Boundary Roughness, Proceedings Second Hydraulic Conference, University of Iowa Bulletin 27, 1943.







TM-272
0122.900

THE WATER TEMP. DEG. C. IS

? 45

INPUT 1 FOR IRON PIPE, 2 FOR DRAWN TUBE, 3 FOR GALV.

DATA LINE 2100 MUST BE COMPATIBLE

? 2,

INVALID INPUT DATA ... RETYPE IT

2

SMOOTH TUBE, INSIDE DIAMETER .1 INCHES
 RELATIVE ROUGHNESS 600.E-6, 45. C. DEG.

GPM	FPS	REY. NO.	PSI/100'	KW/DEG. C.
0.01	0.41	532.	1.6	0.003
0.02	0.82	1064.	3.2	0.005
0.03	1.22	1596.	4.8	0.008
0.04	1.63	2127.	6.5	0.010
0.05	2.04	2659.	*	0.013
0.06	2.45	3191.	*	0.016
0.07	2.86	3723.	*	0.018
0.08	3.26	4255.	34.1	0.021
0.10	4.08	5318.	50.1	0.026
0.20	8.16	10637.	168.0	0.052
0.30	12.24	15955.	343.9	0.079
0.40	16.32	21274.	574.9	0.105

SMOOTH TUBE, INSIDE DIAMETER .12 INCHES
 RELATIVE ROUGHNESS 500.E-6, 45. C. DEG.

GPM	FPS	REY. NO.	PSI/100'	KW/DEG. C.
0.01	0.28	443.	0.8	0.003
0.02	0.57	886.	1.6	0.005
0.03	0.85	1330.	2.3	0.008
0.04	1.13	1773.	3.1	0.010
0.05	1.42	2216.	3.9	0.013
0.06	1.70	2659.	*	0.016
0.07	1.98	3102.	*	0.018
0.08	2.27	3546.	*	0.021
0.10	2.83	4432.	21.1	0.026
0.20	5.67	8864.	70.3	0.052
0.30	8.50	13296.	143.2	0.079
0.40	11.33	17728.	238.5	0.105
0.50	14.17	22160.	355.1	0.131
0.60	17.00	26592.	492.5	0.157

* INDICATES FLOW IN UNSTABLE (TRANSITION) REGION

FLOW 16:37 08/26/70 WEDNESDAY LEA

PAGE 1.

THE WATER TEMP. DEG. C. IS

? 20

INPUT 1 FØR IRØN PIPE, 2 FØR DRAWN TUBE, 3 FØR GALV.

DATA LINE 2100 MUST BE COMPATIBLE

? 1

IRØN PIPE, I.D. .269 INCHES
RELATIVE RØUGHNESS 6691.E-6, 20. C. DEG

GPM	FPS	REY. NØ.	PSI/100'	KW/DEG. C.
0.05	0.28	586.	0.26	0.013
0.06	0.34	703.	0.31	0.016
0.07	0.39	820.	0.36	0.018
0.08	0.45	938.	0.42	0.021
0.10	0.56	1172.	0.52	0.026
0.20	1.13	2344.	1.04	0.052
0.30	1.69	3516.	*	0.079
0.40	2.26	4688.	6.81	0.105
0.50	2.82	5860.	10.20	0.131
0.60	3.38	7032.	14.24	0.157
0.70	3.95	8204.	18.93	0.184
0.80	4.51	9376.	24.32	0.210
1.00	5.64	11721.	36.94	0.262
2.00	11.28	23441.	138.09	0.525

IRØN PIPE, I.D. .364 INCHES
RELATIVE RØUGHNESS 4945.E-6, 20. C. DEG

GPM	FPS	REY. NØ.	PSI/100'	KW/DEG. C.
0.10	0.31	866.	0.15	0.026
0.20	0.62	1732.	0.31	0.052
0.30	0.92	2598.	*	0.079
0.40	1.23	3465.	*	0.105
0.50	1.54	4331.	2.30	0.131
0.60	1.85	5197.	3.18	0.157
0.70	2.16	6063.	4.20	0.184
0.80	2.46	6929.	5.36	0.210
1.00	3.08	8662.	8.07	0.262
2.00	6.16	17323.	29.31	0.525
3.00	9.24	25985.	63.33	0.787
4.00	12.32	34646.	110.12	1.050

* INDICATES FLOW IN UNSTABLE (TRANSITION) REGION.

FLOW

J8 09/22/70 TUESDAY

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PAGE 1.

THE WATER TEMP. DEG. C. IS

? 20

INPUT 1 FOR IRON PIPE, 2 FOR DRAWN TUBE, 3 FOR GALV.

DATA LINE 2100 MUST BE COMPATIBLE

? 3

GALVANIZED IRON PIPE, I.D. .269 INCHES
 RELATIVE ROUGHNESS 22305.E-6, 20. C. DEG

GPM	FPS	REY. NO.	PSI/100'	KW/DEG. C.
0.05	0.28	586.	0.26	0.013
0.06	0.34	703.	0.31	0.016
0.07	0.39	820.	0.36	0.018
0.08	0.45	938.	0.42	0.021
0.10	0.56	1172.	0.52	0.026
0.20	1.13	2344.	1.04	0.052
0.30	1.69	3516.	*	0.079
0.40	2.26	4688.	8.75	0.105
0.50	2.82	5860.	13.37	0.131
0.60	3.38	7032.	18.95	0.157
0.70	3.95	8204.	25.50	0.184
0.80	4.51	9376.	33.02	0.210
1.00	5.64	11721.	50.94	0.262
2.00	11.28	23441.	198.29	0.525

GALVANIZED IRON PIPE, I.D. .364 INCHES
 RELATIVE ROUGHNESS 16484.E-6, 20. C. DEG

GPM	FPS	REY. NO.	PSI/100'	KW/DEG. C.
0.10	0.31	866.	0.15	0.026
0.20	0.62	1732.	0.31	0.052
0.30	0.92	2598.	*	0.079
0.40	1.23	3465.	*	0.105
0.50	1.54	4331.	2.81	0.131
0.60	1.85	5197.	3.95	0.157
0.70	2.16	6063.	5.29	0.184
0.80	2.46	6929.	6.81	0.210
1.00	3.08	8662.	10.42	0.262
2.00	6.16	17323.	39.88	0.525
3.00	9.24	25985.	88.27	0.787
4.00	12.32	34646.	155.59	1.050

* INDICATES FLOW IN UNSTABLE (TRANSITION) REGION.